SIMULATION OF AUTO –TUNING PID CONTROLLER FOR DC MOTOR USING ZIEGLER-NICHOLS METHOD

AINA AZLIYANA BT MOHAMAD

A thesis submitted is fulfillment of the requirements for the award of the degree of Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering

University Malaysia Pahang

JUNE 2012

ABSTRAK

Ziegler-Nichols method is one of the controller methods to control a system in the industry. In this project, the Ziegler-Nichols (ZN) tuning method was Implemented a proportional-Integral-Derivative (PID) controller to control a DC motor. There are so many application use PID controller is more than 90% of closed loop and open loop of industrial processes The main objective is conducted numerous experiments and proposed rules for determining values of Kp, Ki, and Kd based on the transient step response of a plant. In this project, ZN rule is to implement the PID controller transfer function and analysing the response of DC motor with PID controller. For this case, the objective representing the DC motor speed performance, Which is of the DC motor. The speed of the DC motor is identified by the input voltage of the motor and the output will be compared with the input. In this project, ZN and ES method was Implemented in the PID system. The DC motor state space is derived to find the transfer function. The PID controller is then designed circuit system using MATLAB software. This is followed by the manual tuning of PID controller Which is stimulated by using the Ziegler-Nichols method. The result of the project is known the response of better performance by the Ziegler-Nichols rule.

ABSTRAK

Kaedah Ziegler-Nichols adalah salah satu kaedah pengawal untuk mengawal sistem dalam industri. Dalam projek ini, Ziegler-Nichols (Zn) kaedah penalaan telah dilaksanakan berkadar-Kamiran-Terbitan (PID) pengawal untuk mengawal motor AT. Terdapat banyak aplikasi penggunaan pengawal PID adalah lebih daripada 90% daripada gelung tertutup dan gelung terbuka proses industri Objektif utama dijalankan pelbagai eksperimen dan kaedah-kaedah yang dicadangkan untuk menentukan nilai k_p, K_i, dan K_d berdasarkan sambutan langkah fana tumbuhan. Dalam projek ini, ZN kaedah adalah melaksanakan PID rangkap pindah pengawal dan menganalisis tindak balas motor DC dengan pengawal PID. Bagi kes ini, objektif yang mewakili prestasi motor DC yang kelajuan motor AT. Kelajuan motor AT dikenal pasti oleh voltan input motor dan output ini akan dibandingkan dengan input. Dalam projek ini, ZN dan kaedah ES telah dilaksanakan dalam sistem PID. Ruang keadaan motor DC diperolehi untuk mencari rangkap pindah. Litar sistem pengawal PID kemudian direka dengan menggunakan perisian MATLAB. Ini diikuti dengan penalaan manual pengawal PID yang dirangsang dengan menggunakan kaedah Ziegler-Nichols. Hasil daripada projek yang dikenali sambutan yang lebih baik prestasi oleh pemerintahan Ziegler-Nichols.

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LIST OF ABBREVIATIONS

DC	Direct Current
P	Proportional control
PI	Proportional-Integral control
PID	Proportional-Integral-Derivative
ES	Extremum Seeking
ZN	Ziegler Nichols
MATLAB	MATrix LABoratory
M-file	MATLAB text editor file

CHAPTER 1:

INTRODUCTION

1.1 INTRODUCTION

In this chapter introduction is made of some general information about the application of PID controller with DC motor, research study in this project and the essential information of the Ziegler-Nichols tuning method.

1.2 PROBLEM STATEMENT

The DC motor with Proportional-Integral-Derivative (PID) controller is very extensive used in manufacturing application especially in electronic industry. The Ziegler-Nichols rule of tuning is a very significant. However have severe drawbacks.
Ziegler-Nichols have two method to be presented, there is a step response method and frequency response method. So, this thesis is used Ziegler-Nichols tuning rule to achieve possible simple tuning rule of PID controller using DC Motor.

1.3 PROJECT BACKGROUND RESEARCH

This thesis describes the development of Auto-tuning Proportional-Integral-Derivative (PID) controller designed for DC motor speed motor by using Ziegler-Nichols (ZN) tuning rule method. This project is to present a method using ZN simple technique to tune the PID parameters achieved it. ZN method have two special method for tuning PID controller develop by Ziegler and Nichols in the 1940s are still commonly used (Killingsworth. *et al*, 2006). In this project thesis,the objective is to present of DC motor performance which is speed control.

Ziegler and Nichols develop their tuning rules by simulating the large number of different process and control the parameter with the features of the step response. Ziegler and Nichols conducted numerous experiments and proposed rules for determining values of K_p, K_i and K_d based on the transient step response of a plant. Ziegler and Nichols proposed more than one methods, but we will limit as known as the first method of Ziegler-Nichols in this tutorial. It applies to plants with neither integrators nor dominant complex-conjugate poles, whose unit-step response resemble an S-shaped curve with no overshoot.

The main contribution in this project is PID controller. It is commonly used for feedback controller. In (Nascu,, I. et al. 2006),PID is measuring an error value as the differences between process variable (PV) and desired setpoint (target value that automatic control). The PID controller is involving three separate constant parameters. There is Proportional (P) is depend on the present error, Integral (I) is collected the past error and Derivative (D) is will predict the future error. These three combinations of PID are important to increase the speed response, to eliminate the steady state error and also to reduce overshoot (Nascu. *et al*, 2006). The PID controller block diagram shown in Figure 1.1:

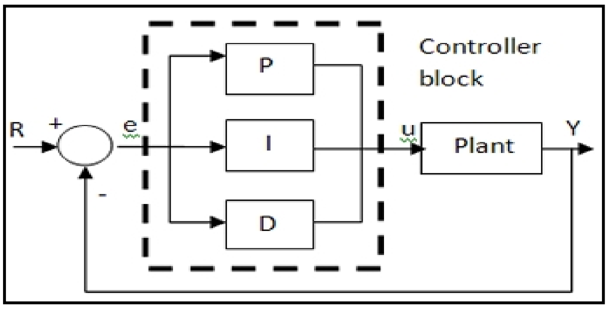

Figure 1.1: PID controller block diagram

The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $u(t)$ as the controller output, the final form of the PID algorithm shown:

$$U(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{d}{dt} e(t) \quad (1.1)$$

Where,

K_p: Proportional gain, a tuning parameter

K_i: Integral gain, a tuning parameter

K_d: Derivative gain, a tuning parameter

e: Error

t: Time or instantaneous time (the present)

The PID controller is widely used in the process industries but the effectiveness is often limited due to poor tuning (Killingsworth. *et al*, 2006). In many situations, the plant model is not known and it is not desirable to open the closed loop for system identification. Thus, a method for tuning PID with closed loop setting is advantageous.

1.4 PROJECT OBJECTIVES

Every project has own objectives. The purpose should have the objectives are to make sure the project follow the need which act as a guide. The objectives of this project are:

i. To simulated the auto-tuning PID controller for DC motor using Ziegler-Nichols tuning method.
ii. To analyze of function response of DC motor PID controller by using Ziegler-Nichols rule.

1.5 PROJECT SCOPES

For every project, the project scopes help to lead the project according to the objective. The project scopes are:

i. This thesis only considers the PID controller for a DC motor

ii. This thesis only deals with simulation using MATLAB

1.6 THESIS ORGANIZATION

This thesis is composed of five chapter with cover the introduction, literature review, methodology, analysis and result and lastly the conclusion and recommendation in the future work.

Chapter 1 is explaining about background and overview of Proportional-Integral Derivative as known as PID controller and Ziegler-Nichols method. It is also consist of problem statement, objectives and also the project scope.

Chapter 2 discusses most of the recent PID controller, DC motor, PID tuning, auto-tuning and Ziegler-Nichols method. All the journals and the books that have attachment to this project are used as references to guide and help the completing this project. Each of this part is explain on finding.

Chapter 3 explains about methodology that has been used in order to complete the project. The parts which are conduct is MATLAB software and m-file. The parameters of the PID controller and the tuning concept were included in this chapter.

Chapter 4 gives a detail result and analysis on the design aspects for the system, which consist of SIMULINK of DC motor and PID controller using MATLAB SIMULINK.

Chapter 5 presents the overall conclusion of development of the project. This chapter also discusses for few suggestion and recommendation for future work modification.

CHAPTER 2:

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it focused more on literature review for each component that has been used in this project. Others components are described in details based on the finding during completion of this project.

2.2 DC MOTOR

DC motor is a motor converts electrical energy into mechanical energy which the motor is coupled to some mechanical load. The motor have to be used in different types of industrial machines tools and for this project the geared DC motor is used. In DC motor, electrical energy is converted into mechanical energy through the interaction of two magnetic fields. One field is produced by magnet assembly which is on the start and the other field is produced by an electrical current flowing in the motor winding for the rotor (Ogata, 2002). As the rotor turns, the current in the windings is commutated to produce a continuous torque output.

DC motor is a common actuator in control system. It directly provides rotary motion and couple with wheels or drums and cables to provide the transitional motion. Some of it is characteristics that can be addressed are to meet the design requirement. Ogata, K. 2002 present the work on DC motor that firstly the motor can only rotate at 1.0 rad/s with and input voltage of 1 volt. Since the most basic instrument of motor should rotate at the desired speed, at steady state error should be less than 1 %.

The other performance requirement of motor is the motor must accelerate to its steady-state speed as soon as it turn on. In this case, the motor should have settling time of 2 seconds. Since speed faster than reference may damage the equipment, it also need have overshoot of less than 5%. By using MATLAB, the original performance can be plot reference input is stimulated by an unit step input (Ogata, 2002). The motor speed output should have settling time less than 2 seconds, overshoot less than 5% and steady-state error is than 1 %.Figure 2.1 shown the step response for open loop system.

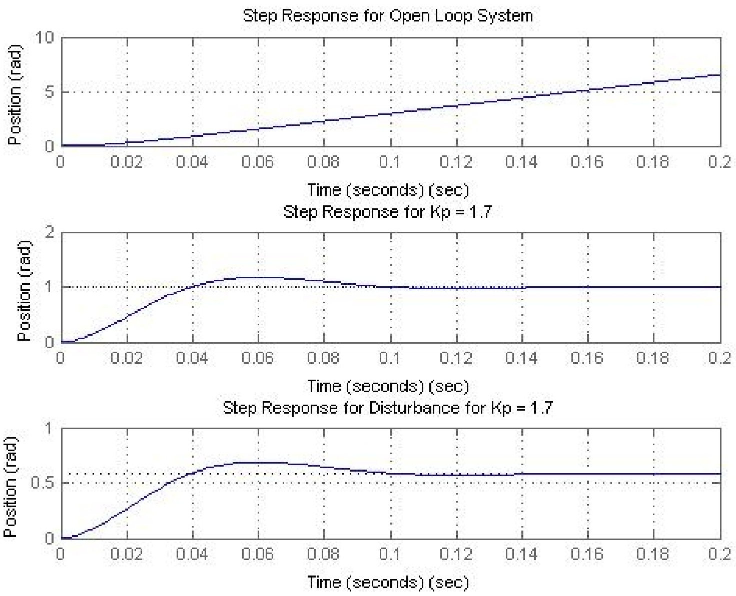

Figure 2.1: Step response for open loop system

(Source: Ogata, 2002)

2.3 PROPORTIONAL-INTEGRAL-DERIVATIVES (PID) CONTROLLERS

PID (proportional-integral-derivative) control is by far the widest type of automatic control used in industry. Even though it has a relatively simple algorithm or structure, there are many fine variations in how it is applied in industry (Ogata, 2002). PID controllers are used in more than 95% of the closed-loop industrial process and most of PID controllers are tune by on-site. Many of the modern controller are much to complex but it often provide marginal improvement and it can be tuned by operators without extensive background.

A PID controller has the general form which is:

$$U(t) = MV(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \tag{1.1}$$

In (Killingsworth, 2006), where K_p is proportional gain, K_i is the integral gain, and K_d is the derivative gain. The PID controller calculation (algorithm) involves three separate parameters there are the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The manual tuning of PID controllers, which require optimization of three parameters, is a time consuming task (Killingsworth, 2006). The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, the power supply of a heating element or DC motor speed and position.

A PID controller is found in large number of company in all industries. The controller is come into different forms. There are many industrial process implement the PID controller. The reason is because it is simple structure and well known Ziegler-Nicholas tuning algorithm have been develop. Other reason is the controlled process in an industrial almost can be controlled by PID controlled with the PID control (Nascu. *et al*, 2006). But, the conventional PID controller design usually needs to retune the parameters like proportional gain, integral time constant and derivative time constant is mutually by the skill operator.

By Nascu *et al*, (2006) present work there are renewed interest in PID controllers because of two reasons. The first reason is they extensively used in application in all industries. Second, despites the existence of some results modern optimal control methods are not suitable to deal with fixed structure and fixed controllers. So, there is much that remains to be done to modernize PID design methods.

Proportional-Integral-Derivatives (PID) controller is one of the most commonly used controllers because of the simplicity and robust. Also, it is suitable for use in control system where the transfer function of the plants has been completely defined. A continues data PID controller can be defined as with gain of each block state independently (Nascu. *et al*, 2006).

The robustness enhancement of DC motor control system, they propose an adaptive PID learning controller which consist of set of learning rules for PID gain tuning and learning of an auxiliary input (Astrom. *et al*, 1993). The proposed PID learning controller is shown to drive the state of uncertain DC motor system with unknown system parameters and external load torque to desired one globally asymptotically.

Closed loop controller is keeping motor speed at require set point under varying load conditions to keep at point value where (Ogata, 2002). For example, the set point is ramping up or down at the define rate. The system works if an error of speed is positive. The motor is running too fast so that the controller output is reduce. If the load is applied the motor is slow down and produce negative error. The output then increase by proportional amount to try and restore the speed.

However, the speed recovers, error reduces and so therefore does the drive level. The result is the motor speed will stabilize at some speed below the set point at which the load is balanced by the error speed time with the gain. If the gain is very high so that event is the smallest changes in motor speed causes a significant change in drive level, the motor speed may be oscillate. The basic strategy is based on proportional control and it have only limited use as it can never force the motor run exactly at the set point speed.

2.4 PID TUNING

There is several methods for tuning a PID. The most useful model shown in Table 2.1, then by the most effective methods generally involve the development of some form of process model, then choosing P, I, and D based on the dynamic model parameters.

Table 2.1: PID tuning methods

	Method	Advantages	Disadvantages
1	Manual tuning	Not math require, online method	Requires experience personnel
2	Ziegler-Nichols	Proven method, online method	Process upset, some try and error, very aggressive tuning
3	Cohen-Coon	Good process model	Some math offline method. Only good for first order process
4	Extremum Seeking	Proven by method	Some math method, good in various tunes.

2.5 PID AUTO-TUNING

From Chien and Jang (2010) state that an auto-tuner is something capable of computing the parameters of a regulator connected to a plant automatically and possibly without any user interaction apart from initiating the operation.auto-tuning method of PID controller is proposed, which combines: modelling of the closed-loop system, modelling of the process, and tuning formulas in terms of the relative damping of the transient response to set point changes.

The auto tuned Proportional-Integral-Derivative (PID) Controllers are designed for applications where large load changes are expected or the need for extreme accuracy and fast response time exists. The PID parameters are tuned based on the results of step response simulations to produce a response with minimal settling time and overshoot.

2.6 ZIEGLER-NICHOLS METHOD

The Ziegler-Nichols method is common used in tuning of PID controllers. The proposed ruled of Ziegler-Nichols method is for determining values of the proportional K_p, integral time T_i and derivative time T_d based on the transient response characteristics of the plant (Rasmussen, 2002). Such as the determination of the parameters of PID controllers or tuning of PID controller can be made on site by experiment on plant.

The following parameter in the PID regulator have to be chosen:

K	proportional gain
T_i	integration time
T_d	derivative time
b	fraction of command signal
N	high frequency limiter of derivative action
U_{min}	minimum saturation value
U_{max}	maximum saturation value
h	sampling time

In this method, it described simple mathematical procedures, the first and second methods respectively for tuning PID controllers. These procedures are accepted as standard in control system practices. Ziegler-Nichols formulae are for specifying controller is based on plant step response. For this project, the first method of Ziegler-Nichols is used to target plant that can be rendered unstable under proportional control. The technique is designed to result in closed loop system with the 25% (Killingsworth, 2006). It is rarely achieve as the adjustment of the specific DC Motor plant.

The step for tuning by using the proportional feedback control:

- Reduce the integrator and derivatives gains to 0.
- Increase K_p from 0 to some critical value $K_p = K_{cr}$ at which sustained oscillations occur. If it does not occur then another method has to applied.
- The value K_{cr} and the corresponding period of sustained oscillation, P_{cr}

The controller gains are specific as in Table 2.2 and Table 2.3 :

Table 2.2: Ziegler-Nichols Tuning Rule Based on step response-first method

Type of Controller	**K_P**	**T_i**	**T_d**
P	$\frac{T}{L}$	∞	0
PI	$0.9\frac{T}{L}$	$\frac{L}{0.3}$	0
PID	$1.2\frac{T}{L}$	$2L$	$0.5T$

Table 2.3: Ziegler-Nichols Tuning Rule Based on step response-second method

Type of Controller	**K_P**	**T_i**	**T_d**
P	$0.5K_{cr}$	∞	0
PI	$0.45\,K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.65\,K_{cr}$	$0.5P_{cr}$	$0.125\,P_{cr}$

To address the difficulty, much effort has been invested in developing systematic tuning method (Killingsworth, 2006) which PID controller is usually used the Ziegler-Nicholas method. The Ziegler–Nichols rules for tuning PID controller have been very influential. The rules do, however, have severe drawbacks, they use insufficient process information and the design criterion gives closed loop systems with poor robustness (Cong and Liang, 2009). The Ziegler and Nichols developed their tuning rules by simulating a large number of different processes, and correlating the controller parameters with features of the step response (Cong and Liang, 2009). So, the process of this method is to obtain the parameters according Ziegler-Nicholas tuning rule can find the desired value.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In order to achieve the aim and objectives of this thesis, there is several method uses. The sequence of the methods has been planned as shown in Figure 3.1. The processes involved in achieving notified objectives by firstly to study the literature review about the topic. After that, PID controller system has be setup by using MATLAB application. The response of the method is analyzing using m-file and SIMULINK in MATLAB software. Block diagram of the process model is used to created of simulation process. Then simulate the PID controller using Ziegler-Nichols method and if the circuit is run. The block diagram for DC Motor with controller with the optimum setting which is K_p, T_i and T_d. Then, after the circuit is successful with the simulation and then collect using data requirement by identify the minimum settling time, percentage overshoot and error from output of the graph response. See Figure 3.1 to clear detail about this project thesis.

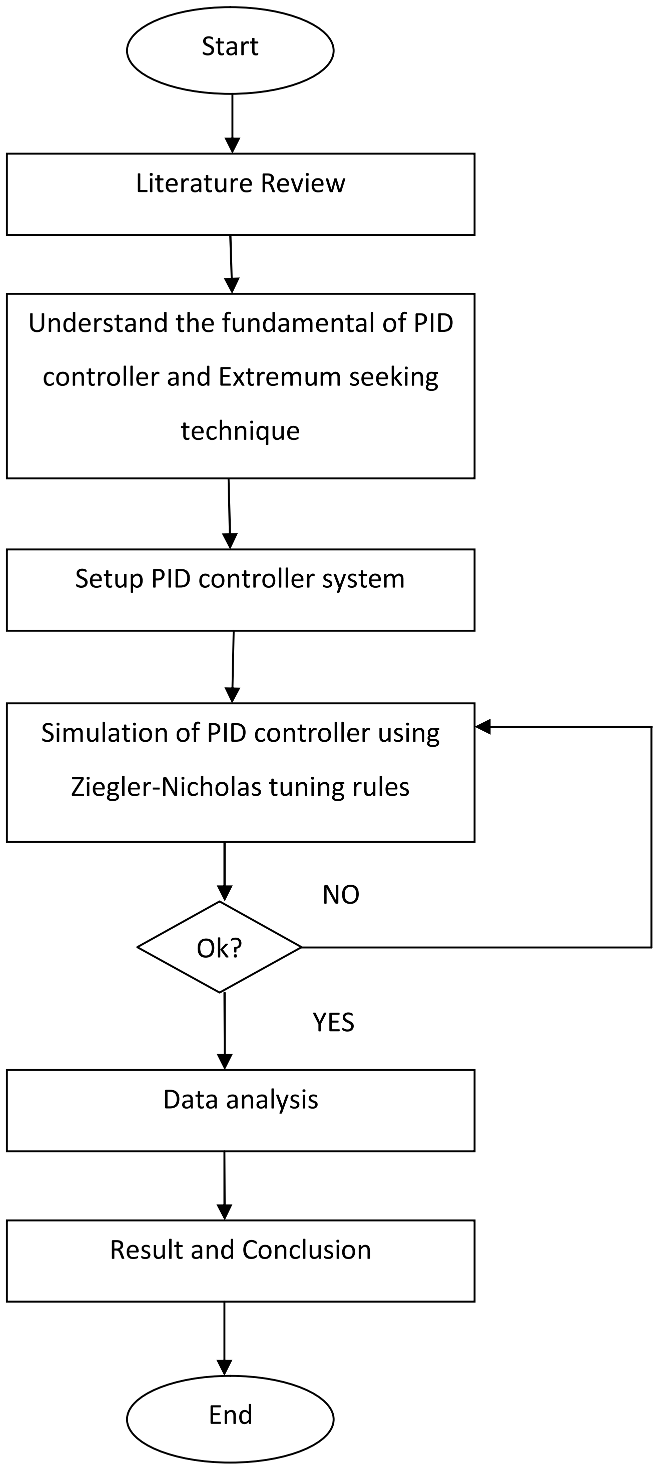

Figure 3.1: Project methodology flow chart